Trace Metal Environments

near Shell Banks in Delaware Bay

Frederick Bopp III & Robert B. Biggs

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NEAR SHELL BANKS IN DELAWARE BAY

Frederick Bopp III
Graduate Student
Department of Geology

and

Robert B. Biggs
Associate Professor of Geology
College of Marine Studies

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College of Marine Studies
University of Delaware
Newark, Delaware
19711

PREFACE

This report represents an interim record of progress during
Fiscal Year 1972 in one aspect of the geological investigation of
Delaware Bay. Preliminary interpretations have been included as
well as appendices presenting the raw data.

The authors felt that the inclusion of a layman's definition
of "part per million" would be beneficial in order to emphasize
to all readers the magnitude of the numbers with which we deal in
trace metals. Dale W. Jenkins, director of the ecology program in
the Office of Environmental Sciences of the Smithsonian Institute
contributed this definition. "The world's driest martini: one ppm
of vermouth would be the equivalent of one ounce of vermouth in
7,800 gallons of gin." (Science, 177: pp. 476-77, 1972)

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of Geology, for taking the samples used, and Frederick K. Lepple,
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and Data Reduction phases of this research.

The National Science Foundation, the National Oceanic and
Atmospheric Administration, and agencies of the State of Delaware
are free to use the contents in any way which serves the public interest,
but are requested to respect the intention of the authors to publish
the formal results of their investigation at a later date.

BACKGROUND

This paper reports the results of research for Fiscal Year 1972 into one aspect of the geological investigation of Delaware Bay. Biggs (1972) presented the results of a sedimentological survey of the oyster reef areas of Delaware Bay. Ninety-two discrete locations were sampled and analyzed for that study. The primary result of the survey was the observation that fine-grained sediments in Delaware Bay are concentrated to a large extent on the Delaware side of the bay. This led to the two-fold hypothesis that either the silts and clays have their source area along the Delaware shore, or there exist conditions for the preferential deposition of silt and clay sized particles along the Delaware shoreline, perhaps due to the Coriolis effect. While there is a vast amount of fine-grained material suspended in the coastal plain estuaries and in the nearshore waters of Delaware Bay, a reliable determination of its source has not yet been made. A corollary to the second hypothesis mentioned above provides the suggestion for a geochemical test of the hypothesis. That corollary was mentioned by Biggs (1972): "if extraneous materials (trace metals, pesticides, etc.) are attached to fine suspended particles, carried downriver, and deposited preferentially on the Delaware shore, then the Delaware side of the Bay is more susceptible to pollution sources from up-river."

INTRODUCTION

The primary objective of Fiscal Year 1972 research is to typify the trace metal geochemical aspects of the sedimentary environments which support oysters in Delaware Bay. These results would provide baseline information to be used in the oyster early-warning pollution monitoring system being developed by the State of Delaware and the University of Delaware under the auspices of the Sea Grant Program. A secondary objective of Fiscal Year 1972 research is to test the hypothesis outlined above. The tertiary objective of this project is an effort to characterize the trace metals determined with respect to 1) their generalized source (i.e., the Delaware River, the ocean, etc.), and 2) the primary factor(s) controlling their distribution.

Most of the original ninety-two samples used by Biggs (1972) had been kept frozen and were used for this research. In addition, twelve samples were obtained from viable oyster reefs in Delaware Bay (labelled B-1, B-2, and B-4 through B-13), and twenty-three samples were obtained which extended the area of investigation to the south and east (labelled SG-101-S-72 through SG-146-S-72). Table 1 is a listing of the positions of the samples from 118 discrete locations used in this project. Sampling and field handling techniques for all samples were those used by Biggs (1972). No sediment analyses are available for the newly procured samples. Figure 1 is a chart of the research area on which the sample positions are plotted.

Table 1:   Positions in Latitude and Longitude
for Delaware Bay Bottom Sediment Grab Samples.

SAMPLE	LAT.	LONG.	SAMPLE	LAT.	LONG.
SG-1A-W-71	39-15.40	75-15.40	SG-42-W-71	39-23.20	75-26.00
SG-1B-W-71	39-15.40	75-15.40	SG-43-W-71	39-21.20	75-23.85
SG-2-W-71	39-14.70	75-16.75	SG-44-W-71	39-20.50	75-24.55
SG-4A-W-71	39-14.00	75-18.25	SG-45-W-71	39-19.90	75-25.20
SG-4B-W-71	39-14.00	75-18.25	SG-46-W-71	39-19.65	75-25.50
SG-5-W-71	39-13.60	75-19.05	SG-47-W-71	39-15.00	75-23.40
SG-6-W-71	39-13.35	75-19.55	SG-48-W-71	39-15.35	75-22.30
SG-7-W-71	39-13.25	75-19.85	SG-49-W-71	39-15.65	75-21.75
SG-8A-W-71	39-13.10	75-20.20	SG-50-W-71	39-15.85	75-21.35
SG-8B-W-71	39-13.10	75-20.20	SG-51-W-71	39-16.10	75-20.60
SG-9-W-71	39-12.60	75-21.05	SG-52-W-71	39-16.65	75-19.75
SG-10-W-71	39-11.95	75-22.20	SG-53-W-71	39-17.25	75-18.95
SG-11-W-71	39-22.50	75.29.05	SG-55-W-71	39-17.35	75-17.80
SG-12-W-71	39-22.40	75-29.65	SG-56-W-71	39-15.35	75-15.50
SG-14-W-71	39-22.80	75-27.30	SG-57-W-71	39-13.95	75-18.35
SG-15-W-71	39-23.00	75-26.35	SG-59-W-71	39-13.00	75-20.35
SG-16-W-71	39-23.15	75-25.90	SG-60-W-71	39-13.90	75-21.10
SG-17-W-71	39-23.10	75-26.10	SG-61A-W-71	39-14.30	75.21.70
SG-18A-W-71	39-22.85	75-26.75	SG-61B-W-71	39-14.30	75-21.70
SG-18B-W-71	39-22.85	75-26.75	SG-62-W-71	39-14.80	75-21.90
SG-19-W-71	39-19.40	75-25.75	SG-63-W-71	39-15.85	75-22.70
SG-20-W-71	39-19.60	75-20.75	SG-64-W-71	49-16.25	75-23.00
SG-21-W-71	39-20.00	75-25.10	SG-65-W-71	39-16.70	75-23.40
SG-22-W-71	39-20.25	75-24.75	SG-66-W-71	39-13.30	75-19.70
SG-23-W-71	39-20.90	75-24.35	SG-67-W-71	39-12.35	75-22.75
SG-24-W-71	39-21.20	75-24.10	SG-68-W-71	39-13.05	75-22.40
SG-25-W-71	39-06.60	75-20.35	SG-70-W-71	39-13.60	75-21.70
SG-26-W-71	39-07.00	75-21.05	SG-71-W-71	39-13.25	75-21.30
SG-27-W-71	39-07.60	75-20.05	SG-72-W-71	39-11.75	75-20.75
SG-28-W-71	39-06.45	75-19.45	SG-73-W-71	39-10.95	75-20.60
SG-29-W-71	39-07.30	75-19.25	SG-74-W-71	39-06.90	75-19.10
SG-30-W-71	39-07.75	75-18.55	SG-75-W-71	39-06.15	75-18.85
SG-31-W-71	39-08.10	75-17.65	SG-76-W-71	39-03.95	75-16.95
SG-32-W-71	39-08.15	75-17.45	SG-77-W-71	39-02.85	75-16.90
SG-33-W-71	39-08.40	75-16.65	SG-78-W-71	39-02.05	75-15.65
SG-34-W-71	39-08.75	75-15.85	SG-80-W-71	39-04.95	75-16.50
SG-35-W-71	39-09.05	75-14.75	SG-81-W-71	39-05.20	75-16.85
SG-36-W-71	39-09.35	75-14.10	SG-82-W-71	39-06.00	75-16.80
SG-37-W-71	39-10.10	75-12.50	SG-83-W-71	39-07.20	75-17.20
SG-39-W-71	39-10.70	75-09.80	SG-84-W-71	39-06.75	75-18.25
SG-40-W-71	39-23.00	75-26.85	SG-85-W-71	39-09.70	75-19.10
SG-41-W-71	39-25.15	75-26.20	SG-86-W-71	39-09.80	75-17.40

Table 1 (cont.)

SAMPLE	LAT.	LONG.	SAMPLE	LAT.	LONG.
SG-87-W-71	39-11.15	75-18.6U	SP-123-S-72	39-U6.1U	75-14.8U
SG-88-W-71	39-21-7U	75-23.8U	SG-124-S-72	39-U6.95	75-14.40
SG-89-W-71	39-2U.35	75-27.10	SG-125-S-72	39-07.25	75-13.7U
SG-9U-W-71	39-21.2U	75-24.10	SG-126-S-72	39-08.4U	75-11.40
SG-1U1-S-72	38-59.8U	75-16.90	SG-127-S-72	39-U9.15	75-1U.30
SG-1U2-S-72	39-UU.5U	75-17.45	SG-128-S-72	39-1U.1U	75-08.2U
SG-1U3-S-72	39-UU.8U	75-16.8U	SG-146-S-72	39-U1.4U	75-U8.20
SG-1U4-S-72	39-U1.35	75-16.25	B-1	39-17.4U	75-23.50
SG-1U5-S-72	39-U2.2U	75-13.60	B-2	39-16.42	75-23.38
SG-1U7-S-72	39-U2.70	75-12.20	B-4	39-12.87	75-22.57
SG-11U-S-72	39-U4.45	75-U8.UU	B-5	39-12.59	75-22.48
SG-111-S-72	39-U7.4U	75-U8.UU	B-6	39-12.32	75-22.32
SG-115-S-72	39-UU.65	75-13.8U	B-7	39-12.60	75-21.68
SG-116-S-72	39-U3.UU	75-18.9U	B-8	39-U4.50	75-2U.25
SG-117-S-72	39-U4.U5	75-21.95	B-9	39-06.87	75-18.10
SG-118-S-72	39-U4.6U	75-20.50	B-10	39-U9.7U	75-20.92
SG-119-S-72	39-U5.2U	75-19.30	B-11	39-15.45	75-21.06
SG-12U-S-72	39-U5.5U	75-18.3U	B-12	39-13.64	75-20.55
SG-121-S-72	39-U5.6U	75-18.05	B-13	39-13.20	75-20.60
SG-122-S-72	39-U5.7U	75-17.7U			

PHILOSOPHY, AND THE CONCEPT OF ENVIRONMENTAL ACTIVITY

The basic philosophy subscribed to in undertaking this research is that the trace metals which are of interest are only those which are available for introduction to the marine food web through naturally occurring biological or chemical processes; i.e., those trace metals which are "environmentally active." Those cations so firmly bonded to-, or exchanged within-, mineral grains that natural biochemical processes cannot remove them are of no concern to this investigation. The laboratory extraction procedure used was designed to approximate, however crudely, the severest conceivable naturally occurring bio-chemical conditions, without completely degrading the sediments.

FIGURE 1: LOCATIONS OF BOTTOM SEDIMENT GRAB SAMPLES IN DELAWARE BAY

NAUTICAL MILES

YARDS

NEW JERSEY
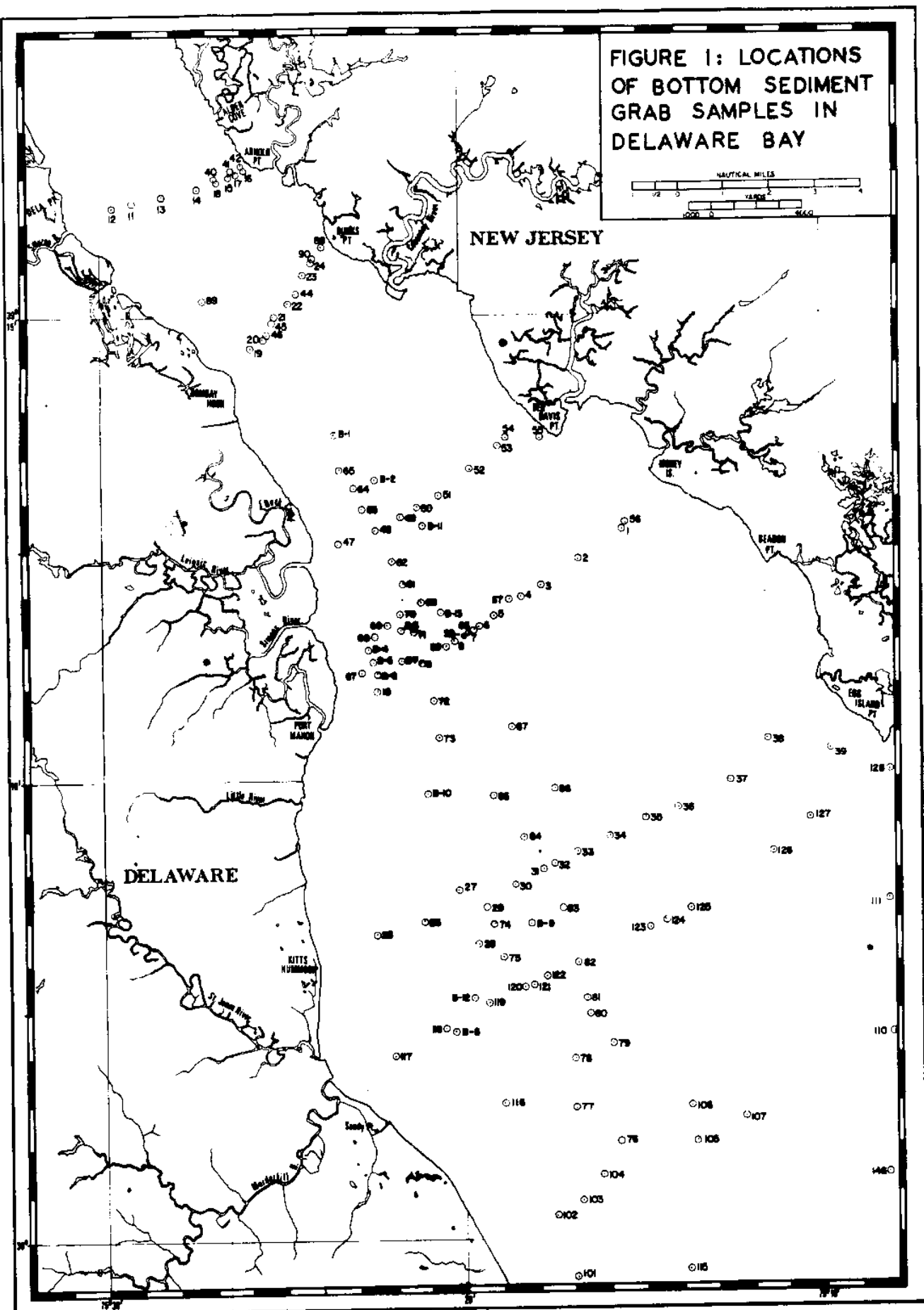
DELAWARE

It must be borne in mind, however, that any given sediment particle enters our laboratory extraction system only once, and then is gone from consideration. In Delaware Bay it is possible for the resident epi- and infauna to recycle the top few centimeters of sediment several times each year, thereby making each particle in the natural habitat available for cation stripping at the very least more than once (see also: Gordon, 1966; and Rhoads, 1963, for examples in other estuarine systems). This is partial justification for making the treatment used here as severe as it is. In addition to this is the fact that the extraction technique used here is a simple, reproducible, inorganic process, whereas the gut-chemistry of even the simplest biological specimen is a complex scheme of enzymes, catalysts and organic acids. The results of the inorganic technique used here are generalized and have a wide range of applications, whereas the results of a biochemical extraction would be species-specific and, therefore, of limited use.

For the purpose of this research the environmentally active trace metals are defined to be those cations which can be separated from 3 grams of dried and disaggregated sediment, from the silt and clay fraction, by leaching with 500 mls, of 10% (vol/vol) HCl in distilled/deionized water at 70°C for 96 hours.

LABORATORY PROCEDURES

General: All solutions used in handling, separating, extracting and analyzing the samples were prepared using distilled/deionized

water, or Fisher Certified A.C.S. solvents. With the exception

of a 3-inch, 63-micron sieve, all laboratory equipment and utensils

used in the handling of the samples were made of polyethylene or

other plastic, or of ceramic, in order to eliminate, insofar as is

economically practical, the probability of outside contamination.

All chemicals used in the analyses were Fisher Certified A.C.S.

Reagents, and all standard solutions were prepared from Fisher

Certified Atomic Absorption Standards.

Silt and Clay Separation: A subsample of each of the samples,

wet weight approximately 250 grams, was transferred to an acid-

washed, double AA-water-washed, 600 ml. plastic beaker. ("AA-water"

is used interchangeably with "distilled/deionized water.") AA-water

was added and the sample aggitated until suspended. The suspensate

was passed through a U. S. Standard No. 230, 63-micron mesh sieve,

and was collected in an acid-washed, double AA-water washed, 1 liter

polyethylene bottle. Then the collected suspensate was centrifuged

at maximum RPM in a Universal Model UV Centrifuge, using Nalgene

tubes, for 30 minutes. The supernatant, containing some non-separable

colloids, was discarded. The sediment particles were transferred to

a 50 ml. plastic beaker and dried at 70°C. The dried sediment was

milled to uniform size, determined only by visual approximation, in

a Spex Industries Model 8000 Mixer Mill, using a ceramic powder

vial and ball. The resulting powder was transferred to a plastic

vial, capped and stored.

Trace Metal Extraction: Polyethylene 500 ml. bottles were pre-treated by leaching with 10% (vol/vol) HCl at 70°C for 96 hours immediately prior to use for trace metal extractions. Subsamples of the dried and disaggregated silts and clays were weighed out at 3.00 $\pm$ 0.001 grams using a Mettler Analytical Balance. The weighed samples were transferred to the acid-treated bottles and 500 mls. of 10% (vol/vol) HCl were added. The acid was prepared by diluting 50 mls. of concentrated HCl (sp. gr. = 1.19) to 500 mls. with AA-water, in order to avoid error due to the electrostriction of the AA-water by the addition of chloride ion. The bottles were capped tightly, shaken vigorously, and heated at 70 $\pm$ 4°C for 96 hours. The bottles were shaken and vented periodically during the course of the heated extraction. When 96 hours had elapsed the solutions were vacuum filtered while hot using a Millipore filtration apparatus with AAWP 0.8 micron filters. The supernatant was returned to the washed bottle in which it had been extracted, capped and stored in a cool place pending analysis.

ANALYTICAL CONDITIONS

General: All analyses were conducted using a Jarrell-Ash Model 800 Atomic Absorption Spectrophotometer in association with twin Honeywell Electronik 17 single-event pen recorders set for 15-inches per hour chart speed. Response of the recorders was 1 second for 1 millivolt full-scale deflection. Hollow cathode lamps used for atomic absorption were all single-element, high spectral output, Jarrell-Ash lamps.

The extraction technique used was designed to yield trace metal
concentrations within the direct-reading limits of the spectro-
photometer for most of the metals of interest. Background corrections
were investigated on a routine basis, but no significant differences
were noted between corrected and uncorrected readings. As the use
of the background correction, B/A mode, reduced the signal-to-noise
ratio, it was not used.

Iron: Iron concentrations were extremely high in the extraction
solutions. A secondary absorption line was selected to allow
accurate determinations to be made. The following analytical
conditions prevailed during the analysis for iron:

Lamp Current	8 ma
Wavelength	3720 $\overset{\circ}{A}$
RB	2.00 (arbitrarily set)
MB	1.96
HVB	-311
Exit Slit Pair	900-1000μ
Mode	% Absorption--Direct
Damping	3 (1-3 scale of reducing noise)
Burner Slot	10 cm.
Flame	air = 15 scfh
	acetylene = 4 scfh
	aux. air = scfh
Detection Limit	0.01 μg/ml
Sensitivity	± 0.05 μg/ml

Magnesium: The magnesium concentrations encountered were too
high to allow the use of the primary 2852 $\overset{\circ}{A}$ line, and they were too
low to allow reliable use of the secondary 2025 $\overset{\circ}{A}$ line in the %
Absorption mode. Therefore, the Absorbance mode was adopted using
the primary wavelength to allow for raising the upper detection

14

limit. The following analytical conditions prevailed during the
analysis for magnesium:

Lamp Current	10 ma
Wavelength	2852 Å
RB	2.00 (arbitrarily set)
MB	2.00
HVB	-340
Exit Slit Pair	75-100μ
Mode	Absorbance--Direct
Damping	3 (1-3 scale of reducing noise)
Burner Slot	10 cm.
Flame	air = 15 scfh
	acetylene = 4 scfh
	aux. air = 4 scfh
Detection Limit	0.0004 μg/ml
Sensitivity	± 0.004 μg/ml

Zinc: These analyses were routine with no unusual conditions. The
following analytical conditions prevailed during the analysis for
zinc:

Lamp Current	7.5 ma
Wavelength	2139 Å
RB	2.00 (arbitrarily set)
MB	2.00
HVB	-470
Exit Slit Pair	75-100μ
Mode	% Absorption--Direct
Damping	3 (1-3 scale of reducing noise)
Burner Slot	10 cm.
Flame	air = 15 scfh
	acetylene = scfh
	aux. air = scfh
Detection Limit	0.003 μg/ml
Sensitivity	± 0.015 μg/ml

Chromium: The signal-to-noise ratio for chromium at the con-
centrations encountered in most of the extraction solutions made
the use of the % Absorption Mode unreliable. The Concentration

mode with full signal expansion was adopted, along with maximum

damping at the pen recorder in complement of the maximum damping

at the spectrophotometer signal output. The following analytical

conditions prevailed during the analysis for chromium:

Lamp Current	10 ma
Wavelength	3579 $\overset{\circ}{A}$
RA	2.00 (arbitrarily set)
MA	2.00
HVA	-390
Exit Slip Pair	150-200μ
Mode	Concentration--10
	(maximum)
Damping	3 (1-3 scale of
	reducing noise)
Burner Slot	10 cm.
Flame	air = 15 scfh
	acetylene = 4 scfh
	aux. air = 4 scfh
Detection Limit	0.005 μg/ml
Sensitivity	$\pm$ 0.06 μg/ml

Copper: The concentrations of copper encountered in the extract

were in the lower end of the reliable detection range. In order

to overcome the low signal-to-noise ratio, the lamp current was

raised above the normal operating currents, and exit slits were

opened wide to allow the maximum throughput of energy. The

following analytical conditions prevailed during the analysis

for copper:

Lamp Current	15 ma
Wavelength	3247 $\overset{\circ}{A}$
RA	2.00 (arbitrarily set)
MA	1.36
HVA	-330
Exit Slit Pair	900-1000μ
Mode	% Absorption--Direct
Damping	3 (1-3 scale of
	reducing noise)

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Burner Slot                    10 cm.
Flame                          air = 15 scfh
                               acetylene = 4 scfh
                               aux. air = 4 scfh
Detection Limit                0.003 µg/ml
Sensitivity                    ± 0.04 µg/ml
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Lead: The concentrations of lead encountered in the sediment

extract were in the lower limits of reliable detection. However,

use of the secondary 2833Å line was required because the signal-

to-noise ratio on the primary 2170Å line approached unity. Despite

the low signal-to-noise ratio, reproducible standard curves were

recorded on three occasions using the secondary wavelength. No

further steps were taken to enhance the signal. The following

analytical conditions prevailed during the analysis for lead:

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Lamp Current                   5 ma
Wavelength                     2833 Å
RA                             2.00 (arbitrarily set)
MA                             1.75
HVA                            -490
Exit Slit Pair                 150-200µ
Mode                           % Absorption--Direct
Damping                        3  (1-3 scale of
                                     reducing noise)
Burner Slot                    10 cm.
Flame                          air = 15 scfh
                               acetylene = 4 scfh
                               aux. air = 4 scfh
Detection Limit                0.03 µg/ml
Sensitivity                    ± 0.30 µg/ml
```

Cadmium: The concentrations of cadmium encountered were so low

as to discourage any confidence in the data. Signal-to-noise

ratio in these concentrations is virtually 1, with several samples

registering concentrations equal to the Detection Limit for

direct reading. Attempts to use the concentration mode only served to

lower the signal-to-noise ratio further. Despite the low level of

confidence in the data, the method did yield reproducible standard

curves, and so the results are presented. The following analytical

conditions prevailed during the analysis for cadmium:

Lamp Current	8 ma
Wavelength	2288 Å
RB	2.00 (arbitrarily set)
MB	1.90
HVB	-540
Exit Slit Pair	425-500µ
Mode	% Absorption--Direct
Damping	3 (1-3 scale of reducing noise)
Burner Slot	10 cm.
Flame	air = 15 scfh
	acetylene = 4 scfh
	aux. air = 4 scfh
Detection Limit	0.003 µg/ml
Sensitivity	± 0.02 µg/ml

Mercury: Mercury analyses were performed using a flameless, cold

vapor technique, in which a quartz cell replaces the burner head.

The quartz cell is aligned in the optical beam path, and is

attached to a compressed air circulatory system and a series of

gages and stopcocks. The system was purged by running air through

the plumbing into the quartz cell and venting while the spectro-

photometer was tuned. Two-ml aliquots of the extraction solution

were pipetted into ground glass reaction vessels. Mercury bound

inorganically within the solutions was reduced to elemental Hg

by the addition of 0.3 ml stannous chloride solution (20% wt/vol

in concentrated HCl). The elemental mercury was carried by the

air stream into the quartz cell. The flameless vapor technique

is highly sensitive, and has an upper limit of reliability of

200 nannograms of mercury per aliquot. Reliable concentrations

of Hg were read in the 0.2-5.0 ppb range. Calibration was

accomplished with a 10 ppb standard, and linearity was assumed

between zero and 10 ppb. The following analytical conditions

prevailed during the analysis for mercury:

Lamp Current	5 ma
Wavelength	2537 Å
RB	2.00 (arbitrarily set)
MB	1.87
HVB	-395
Exit Slit Pair	900-1000μ
Mode	Concentration--10 (maximum)
Damping	3 (1-3 scale of reducing noise)
Air Pressure to Cell	0.5 scfh
Detection Limit	0.2 nannograms/ml
Sensitivity	± 0.15 nannograms/ml

Nickel: In trying to analyze for nickel by direct aspiration

the signal-to-noise ratio approached 1 in all modes of operation.

An evaporation was carried out which yielded a 2.5X concentrated

solution. The flame was tuned down to extremely lean conditions,

and no auxilliary oxidant was used. These measures brought the

signal-to-noise ratio to within acceptable limits, and reliable

results were obtained. The following conditions prevailed during

the analysis for nickel:

Lamp Current	10 ma
Wavelength	2320 Å
RA	2.00 (arbitrarily set)
MA	1.80
HVA	-620
Exit Slit Pair	75-100μ
Mode	% Absorption-- Direct, 2.5X
Damping	3 (1-3 scale of reducing noise)

Burner Slot	10 cm.
Flame	air = 15 scfh
	acetylene = 2 scfh
	aux. air = 0 scfh
Detection Limit	0.01 µg/ml
Sensitivity	± 0.1 µg/ml

Strontium: Analysis for strontium was carried out in the flame

emission mode, using a nitrous oxide/acetylene flame. The signal-

to-noise ratio was moderately favorable and reasonable reproduci-

bility of the standard curves was attained. However, a gradual

decline in sensitivity was noted as analyses proceeded. The

manufacturer provides no sensitivity specification for metals

detected by flame emission--it was assumed that the sensitivity

was one order of magnitude more coarse than the detection limit.

The following analytical conditions prevailed during the analysis

for strontium:

Wavelength	4607 Å
Mode	Flame Emission
Flame	nitrous oxide = 9 scfh
	acetylene = 6 scfh
	aux. N_2O = 4 scfh
Zero Setting	3.08
Sensitivity Setting	7.66
Detection Limit	0.005 µg/ml
Sensitivity	± 0.05 µg/ml

EMISSION SPECTROPHOTOMETRY

Prior to accomplishing the analyses outlined above, it was

desirable to determine gross presence-absence, and rough approxi-

mations of concentrations, of the trace metals of interest here.

Of the many methods available to determine total chemistry of a

sediment sample, emission spectrophotometry was chosen. The new

samples from the oyster reefs were separated as described above,

and small amounts of each of these samples were sent to the E. I.

DuPont de Nemours Co., Wilmington, Delaware for emission spectro-

photometric determinations. Along with these samples were sent samples

of bottom sediments from each of the larger tributary tidal estuaries

which empty into Delaware Bay, and samples of dried oyster tissues

from each of the 25 sites sampled. The results of emission

spectrophotometric determinations are tabulated here in Appendix A.

RESULTS

Table 2 contains a tabulation of all the concentrations of

trace metals determined during Fiscal Year 1972 research. These

concentrations are expressed as micrograms per gram, or parts

per million, of sediments finer than 63 microns.

The values presented in Table 2 were used to plot the

geographic variations among the ten metals determined on the chart

of the research area presented as Figure 1. Figures 2 through 11

are plots of the geographic variations in Delaware Bay bottom sediments

of iron, magnesium, zinc, chromium, copper, lead, cadmium, mercury,

nickel and strontium, respectively. Contour intervals for each plot

were chosen to satisfy the following conditions: 1) contour intervals

had to be of a uniform interval, 2) they had to bracket approximately

90% of all the data, and 3) the intervals had to be broad enough

to illustrate general trends without the introduction of specific

Table 2:   Concentrations of Trace Metals in Delaware Bay
Bottom Sediments, Expressed as Parts Per Million of the
<63 micron Sediment Fraction.   (Mercury listed in PPB)

SAMPLE	Fe	Mg	Zn	Cr	Cu	Pb	Cd	Hg	Ni	Sr
SG-1A-W-71	34500	6850	388	113	96	103	3.8	908	625	161
SG-1B-W-71	39350	8000	495	127	68	107	4.2	983	725	160
SG-2-W-71	43350	9400	475	133	43	103	2.5	975	895	130
SG-4A-W-71	44000	7950	168	100	34	73	2.5	708	600	117
SG-4B-W-71	32650	4150	78	33	9	50	0.8	113	625	56
SG-5-W-71	42350	7400	522	117	65	167	3.3	1142	850	117
SG-6-W-71	49150	6650	363	113	58	137	2.2	958	1167	70
SG-7-W-71	42650	7150	435	100	40	117	2.7	792	175	110
SG-8A-W-71	45000	6500	400	92	85	167	2.5	1291	1035	53
SG-8B-W-71	44000	7950	413	86	62	113	2.5	917	225	94
SG-9-W-71	42850	8500	500	111	47	103	4.2	917	770	114
SG-10-W-71	37150	7550	317	80	34	83	2.2	783	592	105
SG-11-W-71	28500	4400	278	130	50	157	2.5	750	478	53
SG-12-W-71	33150	3850	290	113	43	162	1.7	825	492	40
SG-14-W-71	33000	6850	1875	119	163	250	8.3	1783	650	46
SG-15-W-71	42150	5400	875	150	108	200	3.8	792	675	46
SG-16-W-71	33650	3700	67	95	86	54	1.0	133	525	32
SG-17-W-71	32500	4250	345	108	43	93	2.5	358	358	52
SG-18A-W-71	46350	6900	1100	133	74	208	2.7	1350	775	67
SG-18B-W-71	47500	7050	558	161	102	152	1.0	783	775	59
SG-19-W-71	17350	2650	48	80	50	25	0.8	133	295	48
SG-20-W-71	39350	4050	287	150	50	78	1.6	783	500	53
SG-21-W-71	43150	8400	100	83	18	25	0.8	86	417	56
SG-22-W-71	26850	4850	80	62	18	20	0.8	108	342	48
SG-23-W-71	41500	4100	1200	150	75	205	2.5	2275	925	155
SG-24-W-71	57650	7400	2667	282	98	1083	3.3	975	1717	121
SG-25-W-71	37150	6250	288	120	25	73	2.2	725	545	62
SG-26-W-71	37650	7550	317	153	40	167	1.0	558	403	59
SG-27-W-71	32650	5850	357	133	43	88	2.5	1292	425	80
SG-28-W-71	37250	7000	400	192	115	184	3.7	536	592	77
SG-29-W-71	32000	7300	342	153	40	54	0.8	583	367	210
SG-30-W-71	26500	4650	217	168	28	44	0.6	500	283	56
SG-31-W-71	35650	7250	442	175	43	66	1.7	725	358	75
SG-32-W-71	36650	7500	353	212	43	73	2.5	808	462	75
SG-33-W-71	38150	9150	310	247	52	103	4.5	583	545	267
SG-34-W-71	52000	10250	683	268	65	157	4.3	2150	873	155
SG-35-W-71	41250	8650	312	209	41	96	2.5	863	717	144
SG-36-W-71	41150	9150	412	187	51	113	2.2	766	808	94
SG-37-W-71	27350	8150	435	199	209	167	4.3	1149	617	506
SG-39-W-71	35350	8100	637	139	40	100	4.5	833	650	205
SG-40-W-71	47150	5150	222	167	62	63	3.2	371	833	45

Table 2 (cont.)

SAMPLE	Fe	Mg	Zn	Cr	Cu	Pb	Cd	Hg	Ni	Sr
SG-41-W-71	36000	6250	100	179	86	73	2.0	86	583	40
SG-42-W-71	37850	6300	110	158	173	78	1.5	200	378	38
SG-43-W-71	41650	7500	833	249	77	267	2.3	1625	1045	148
SG-44-W-71	50000	7800	5833	447	252	890	11.3	1666	3633	520
SG-45-W-71	27000	5750	83	208	18	47	2.2	156	608	43
SG-46-W-71	28500	4250	203	216	86	142	1.5	725	608	32
SG-47A-W-71	33500	5550	267	159	68	217	2.3	600	617	32
SG-47B-W-71	26500	4400	192	148	28	68	2.2	408	625	27
SG-48-W-71	34000	7600	305	193	33	78	1.5	642	637	112
SG-49-W-71	31500	6650	383	185	43	73	1.5	600	762	107
SG-50-W-71	43350	8450	525	258	58	225	3.5	875	925	121
SG-51-W-71	41850	10150	408	205	56	183	3.2	2058	750	235
SG-52-W-71	32000	6100	167	148	22	59	1.0	183	670	70
SG-53-W-71	44000	8900	440	277	171	375	2.3	1750	943	154
SG-55-W-71	31250	4400	95	250	260	250	1.5	938	463	23
SG-56-W-71	36850	7050	105	227	135	37	0.8	100	550	15
SG-57-W-71	33350	6550	90	256	34	21	1.5	128	508	32
SG-59-W-71	28850	5750	333	184	40	88	1.5	750	537	43
SG-60-W-71	37000	7850	442	362	80	208	2.2	1058	692	93
SG-61A-W-71	37000	7550	422	280	68	131	2.2	1917	---	74
SG-61B-W-71	28850	4650	125	110	47	88	1.0	371	667	23
SG-62-W-71	30850	5200	325	200	71	63	2.0	630	500	27
SG-63-W-71	40650	8700	375	185	47	88	2.3	558	492	83
SG-64-W-71	38350	6900	103	128	77	37	1.0	228	570	27
SG-65-W-71	41350	7000	595	174	250	242	1.0	825	775	32
SG-66-W-71	45150	8350	1042	265	71	200	3.2	2916	767	68
SG-67-W-71	26000	5600	325	143	40	47	1.5	350	453	37
SG-68-W-71	25000	4600	242	167	38	83	0.6	433	442	78
SG-70-W-71	24150	3700	96	178	47	68	1.0	175	375	74
SG-71-W-71	28650	4700	588	216	68	146	1.7	458	528	74
SG-72-W-71	31000	6900	350	188	40	124	2.5	562	428	78
SG-73-W-71	29150	6300	458	158	28	93	2.5	562	442	78
SG-74-W-71	15900	4100	267	145	49	56	2.5	197	183	146
SG-75-W-71	44500	9150	483	206	89	155	2.7	96	603	205
SG-76-W-71	38350	9050	262	193	56	68	2.7	1458	508	205
SG-77-W-71	42000	8200	420	276	49	131	3.3	1442	558	140
SG-78-W-71	20650	2050	138	227	25	66	2.0	1033	303	41
SG-80-W-71	54850	9900	372	392	100	183	3.3	1708	742	215
SG-81-W-71	67250	10500	560	196	109	300	3.8	4413	1038	219
SG-82-W-71	55150	9150	640	267	63	241	3.3	1375	903	230
SG-83-W-71	41150	8350	373	267	63	111	2.0	691	658	109
SG-84-W-71	23850	4400	237	160	46	88	2.0	113	370	157
SG-85-W-71	26650	4450	222	250	35	66	1.7	408	433	99
SG-86-W-71	26750	4900	200	250	48	91	2.5	267	363	125

Table 2 (cont.)

SAMPLE	Fe	Mg	Zn	Cr	Cu	Pb	Cd	Hg	Ni	Sr
SG-67-W-71	31833	5500	292	203	73	138	1.7	475	475	93
SG-68-W-71	38500	8050	800	340	54	208	4.0	4700	455	522
SG-69-W-71	31650	5100	90	160	43	26	1.3	161	425	60
SG-90-W-71	46500	5100	212	232	143	292	1.0	475	742	50
SG-101-S-72	30850	6850	233	118	49	83	1.3	250	475	50
SG-102-S-72	38350	8450	290	227	63	118	2.0	475	478	125
SG-103-S-72	32350	7150	230	232	59	99	1.7	350	403	125
SG-104-S-72	37000	7200	295	238	86	188	1.7	250	478	140
SG-105-S-72	42350	7600	283	205	63	111	2.0	313	608	161
SG-107-S-72	32250	8050	243	205	84	99	3.6	345	438	763
SG-110-S-72	27650	6350	217	155	333	155	1.3	325	403	93
SG-111-S-72	30500	9000	300	355	95	138	2.0	590	510	535
SG-115-S-72	36500	8050	225	197	49	83	1.3	313	542	140
SG-116-S-72	42350	10850	525	214	225	188	1.7	396	692	297
SG-117-S-72	26000	5000	202	113	32	83	1.0	650	303	64
SG-118-S-72	26650	5200	203	190	39	86	1.0	288	358	97
SG-119-S-72	24650	5600	205	125	49	99	1.0	458	342	64
SG-120-S-72	23000	5100	175	118	35	99	0.7	371	358	69
SG-121-S-72	35650	7400	300	178	53	208	1.0	350	487	178
SG-122-S-72	63500	9700	420	313	84	400	2.0	433	505	140
SG-123-S-72	36350	7050	343	208	56	131	1.7	360	525	89
SG-124-S-72	43000	9650	485	303	93	250	2.5	417	542	272
SG-125-S-72	26500	6150	223	143	39	105	1.3	325	342	125
SG-126-S-72	40850	8650	400	130	76	124	1.0	408	600	248
SG-127-S-72	24850	6350	303	178	89	105	3.3	313	320	751
SG-128-S-72	33650	6650	183	150	76	105	1.7	350	283	78
SG-146-S-72	44150	8650	313	197	60	175	1.3	328	537	156
B1	28350	4700	143	140	18	31	1.7	208	403	45
B2	36500	5150	372	184	76	118	1.3	550	512	64
B4	32850	6900	283	124	35	83	1.3	338	467	64
B5	33850	6950	336	103	39	118	1.3	328	428	74
B6	32350	6400	280	130	39	105	1.7	242	353	89
B7	31000	5900	338	178	53	83	1.0	208	320	69
B8	30350	6500	237	103	35	77	1.7	383	342	93
B9	29850	6600	265	114	56	72	2.0	733	458	115
B10	34850	7400	327	187	79	118	2.0	405	487	93
B11	34350	6200	77	130	25	41	1.7	153	492	55
B12	35650	6600	362	145	56	111	1.7	478	475	60
B13	25850	5400	205	140	25	66	1.3	277	392	60

24

trends which may or may not be capable of substantiation.

SOURCES OF ERROR

With any tedious and repetitive laboratory process there are always ample opportunities for contamination of a sample or two by simple human error. The errors which are most costly, however, are those arising from faulty design of the test procedures. In the procedures used here there are at least five places where significant error may be introduced, either in the form of contaminants or in analytical error. The four major sources of consistent contamination probability are as follow: 1) use of distilled/deionized water which has been contaminated or improperly distilled, 2) contamination due to contact of the sample with the metal sieve during sample preparation, 3) loss of metals due to the discarding of the colloid-containing supernatant after centrifuging, and 4) contamination from the millipore filter during the filtration of the hot extraction solutions. Each of these four sources was tested for detectable contaminant levels.

Five hundred ml aliquots of the solutions from each of the possible contaminating steps were measured into 1 liter volumetric flasks. The pH was adjusted to 2.8 by the addition of Bromphenol Blue indicator and the dropwise addition of concentrated HCl. A chelation-extraction yielded a fifty-fold concentration of the metals present due to contamination. Ten ml of 1% Ammonium Pyrrolidine Dithiocarbamate (APDC) were added, shaken vigorously

and allowed to react for 15 minutes. The metal-APDC chelates were extracted with 10 ml of Methyl Isobutyl Ketone (MIBK) and the ketone layer aspirated directly into the flame of the spectrophotometer. Several of the metals with high concentrations in the bay were analyzed for—iron, magnesium, zinc, and nickel—with negative results in all but the colloid-discarding sample. However, the level noted was not inordinately high—on the order of several hundred ppb iron, several tens of ppb magnesium, traces of zinc and no nickel. Considering that the sample preparation was carried out on samples still containing bay water, these metal levels probably represent ions from the bay pore waters taken into solution during sample preparation.

A one-liter aliquot of the colloid-discarding supernatant solution was vacuum filtered using a Millipore filtration apparatus with an HAWP 0.45 micron filter. The retained particulate material weighed 0.0017 grams, or 0.006% of the nominal yield of 30 grams of fine grained material from the sample preparation procedure previously described. This is well below the 0.03% error already found acceptable in the extraction technique previously described, and, therefore, is not considered to be an important source of error.

The last source of error is the machine error caused by resolution limitations inherent in the design of the atomic absorption spectrophotometer. Listed in the analytical conditions for each metal was the "sensitivity," or resolution limit of the machine. In converting the concentration readings determined for the extraction

solutions into concentrations in the finer than 63-micron fraction,

the conversion factor of 1/3 was used. Table 3 is a tabulation of the

manufacturer's specifications for sensitivity. These specifications

were met for all metals except Fe and Mg, since all readings were

made by direct determination.

Table 3: Sensitivities for the Data Presented
in Table 2, Expressed as ± Parts Per Million
of the <63 Micron Sediment Fraction.

Metal	Sensitivity
Fe	0.05 ppm
Mg	0.004 ppm
Zn	0.015 ppm
Cr	0.06 ppm
Cu	0.04 ppm
Pb	0.30 ppm
Cd	0.02 ppm
Hg	0.15 ppb
Ni	0.10 ppm
Sr	0.05 ppm

DISCUSSION

When one looks over Table 2 and Figures 2 through 11, one is

immediately struck by the extremely high values obtained for iron

and magnesium. There are a number of factors influencing the high

levels of iron and magnesium, and also their distribution around the

Bay. The greatest influence is the fact that chlorite, which is one

of the more common clay minerals in Delaware Bay bottom sediments,

is soluble in hydrochloric acid. One would expect that iron and

magnesium would be in high concentration because both are primary

constituents of chlorite. However, one is struck by the great

FIGURE 2: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Fe IN DELAWARE BAY BOTTOM SEDIMENTS (<63μ FRACTION)

FIGURE 3: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Mg IN DELAWARE BAY BOTTOM SEDIMENTS (<63µ FRACTION)

NEW JERSEY

DELAWARE
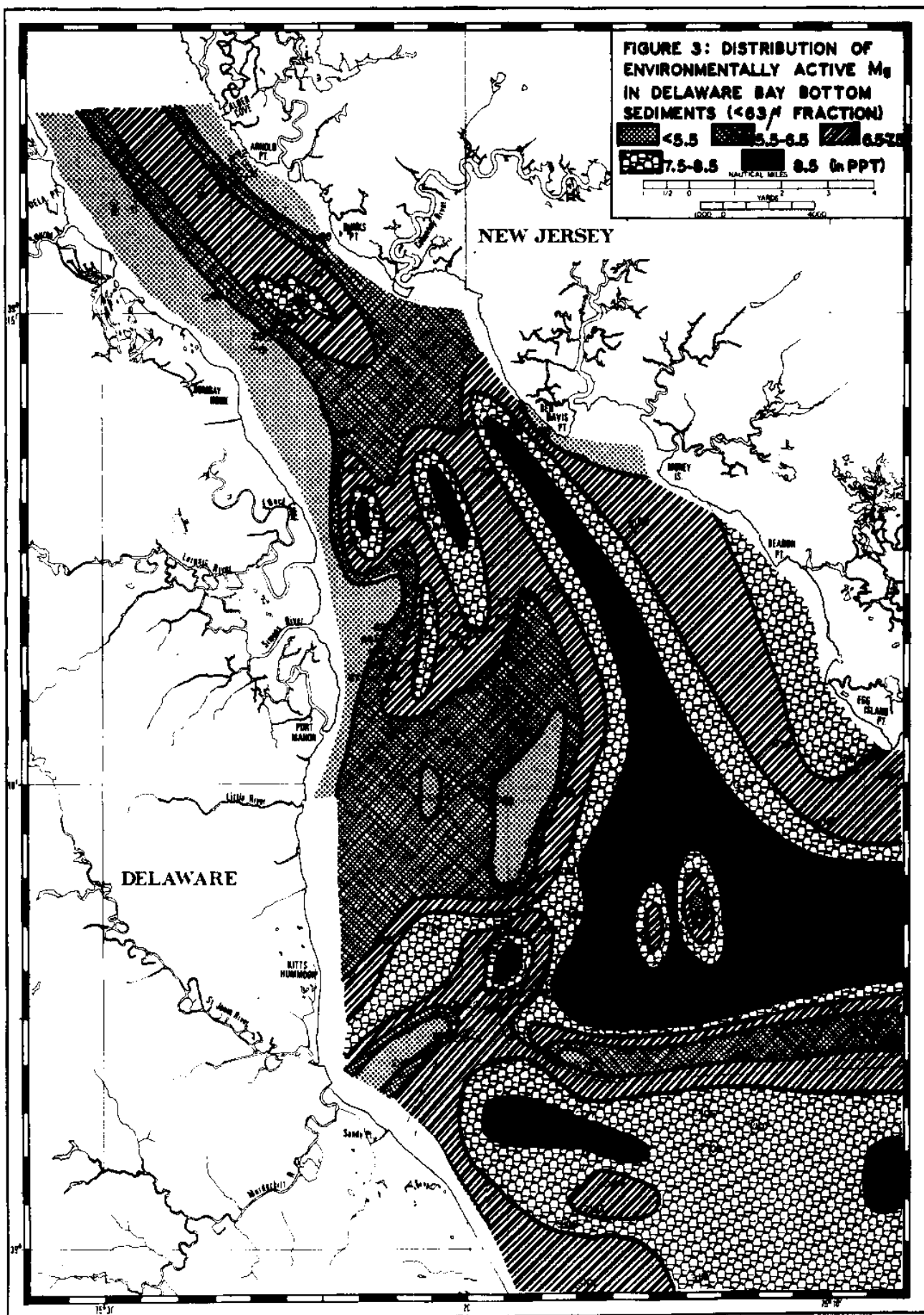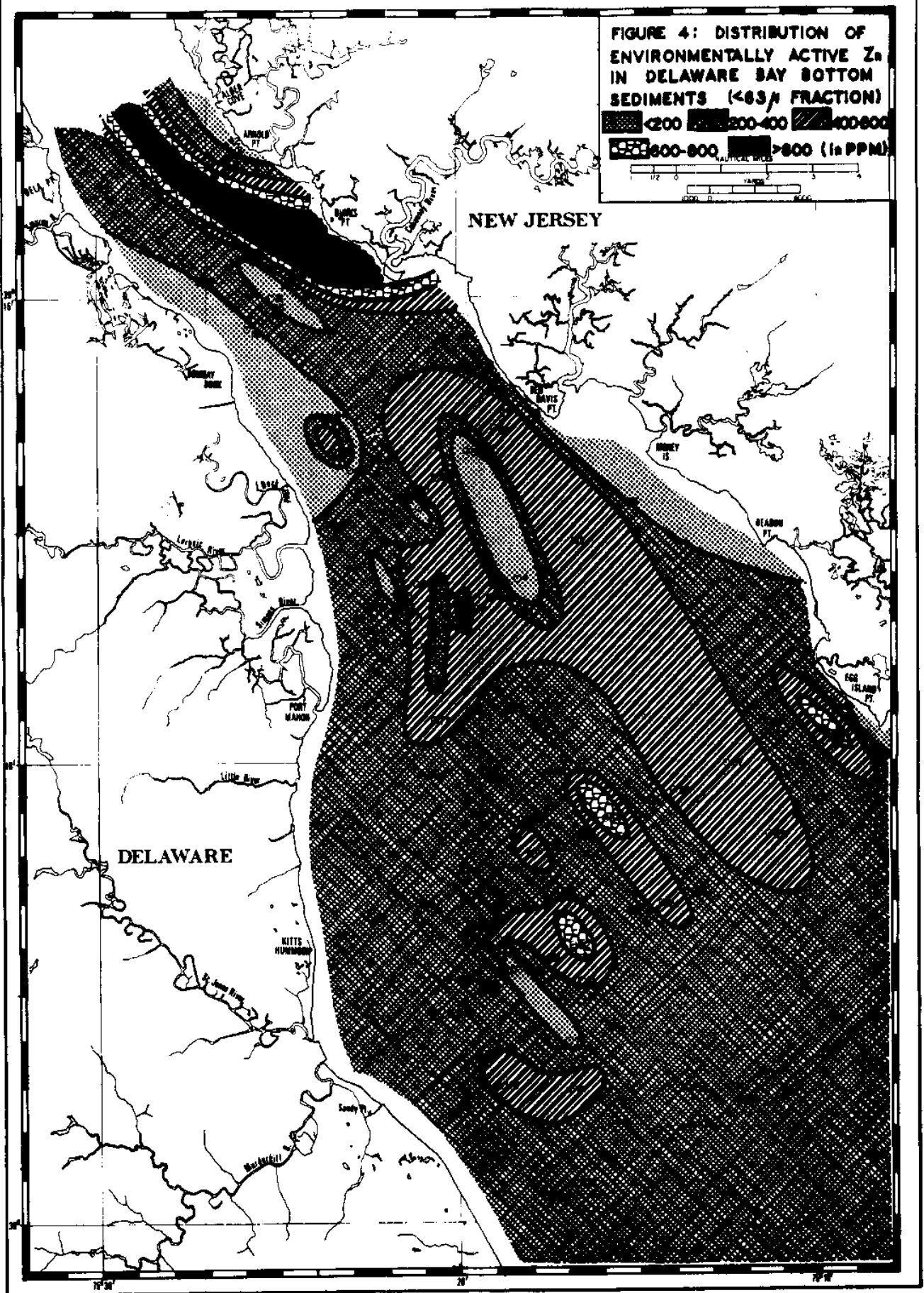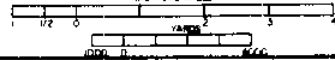
28
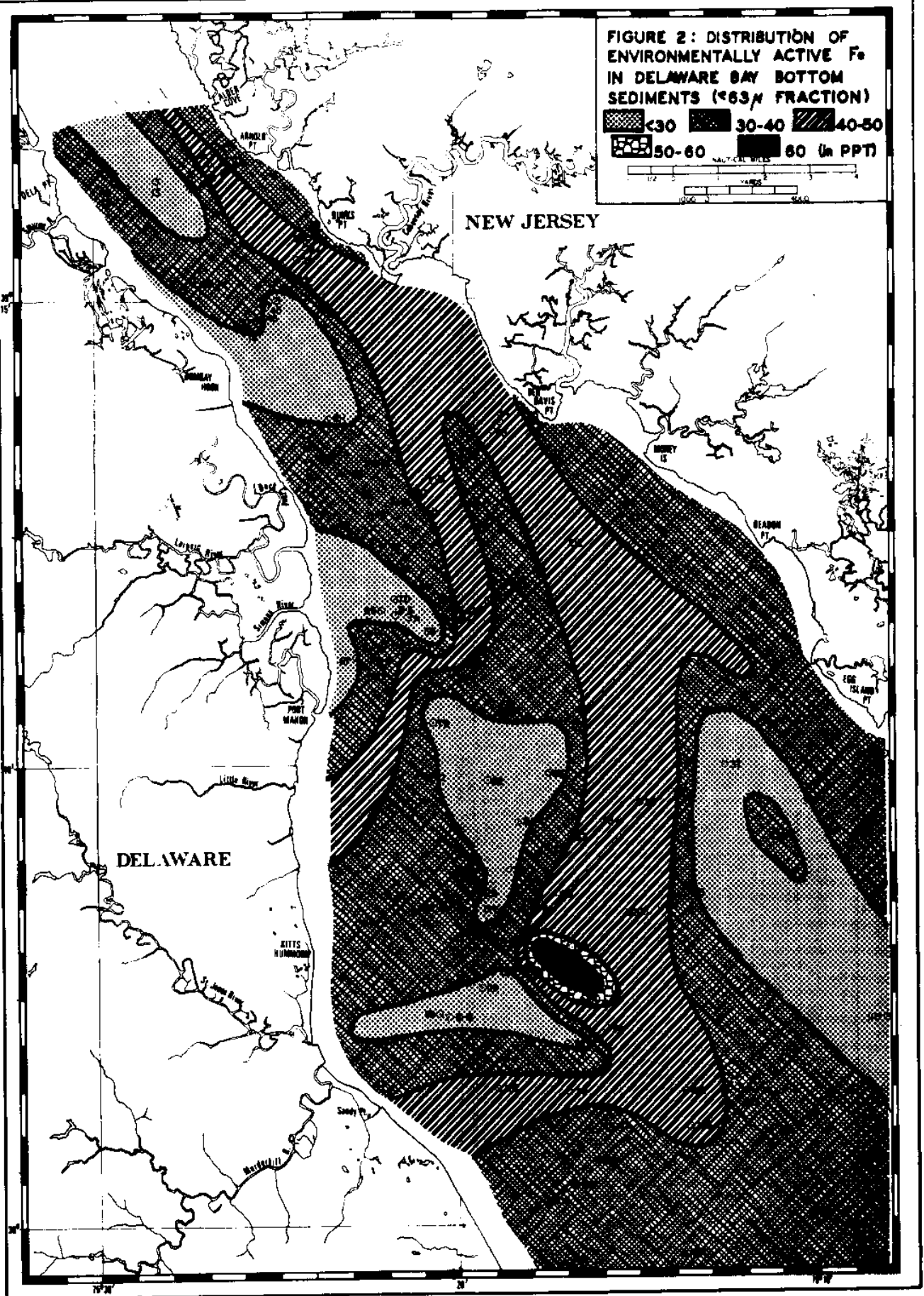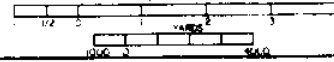
FIGURE 4: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Zn IN DELAWARE BAY BOTTOM SEDIMENTS (<63μ FRACTION)

<200   200-400   400-600   600-800   >800 (in PPM)

FIGURE 5: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Cr IN DELAWARE BAY BOTTOM SEDIMENTS (< 63 μ FRACTION)

FIGURE 6: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Cu IN DELAWARE BAY BOTTOM SEDIMENTS (<63 μ FRACTION)

<25   25-50   50-75   75-100   >100 (in PPM)

NAUTICAL MILES

YARDS

NEW JERSEY

DELAWARE

FIGURE·7: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Pb IN DELAWARE BAY BOTTOM SEDIMENTS (<63 μ FRACTION)

NEW JERSEY

DELAWARE

32
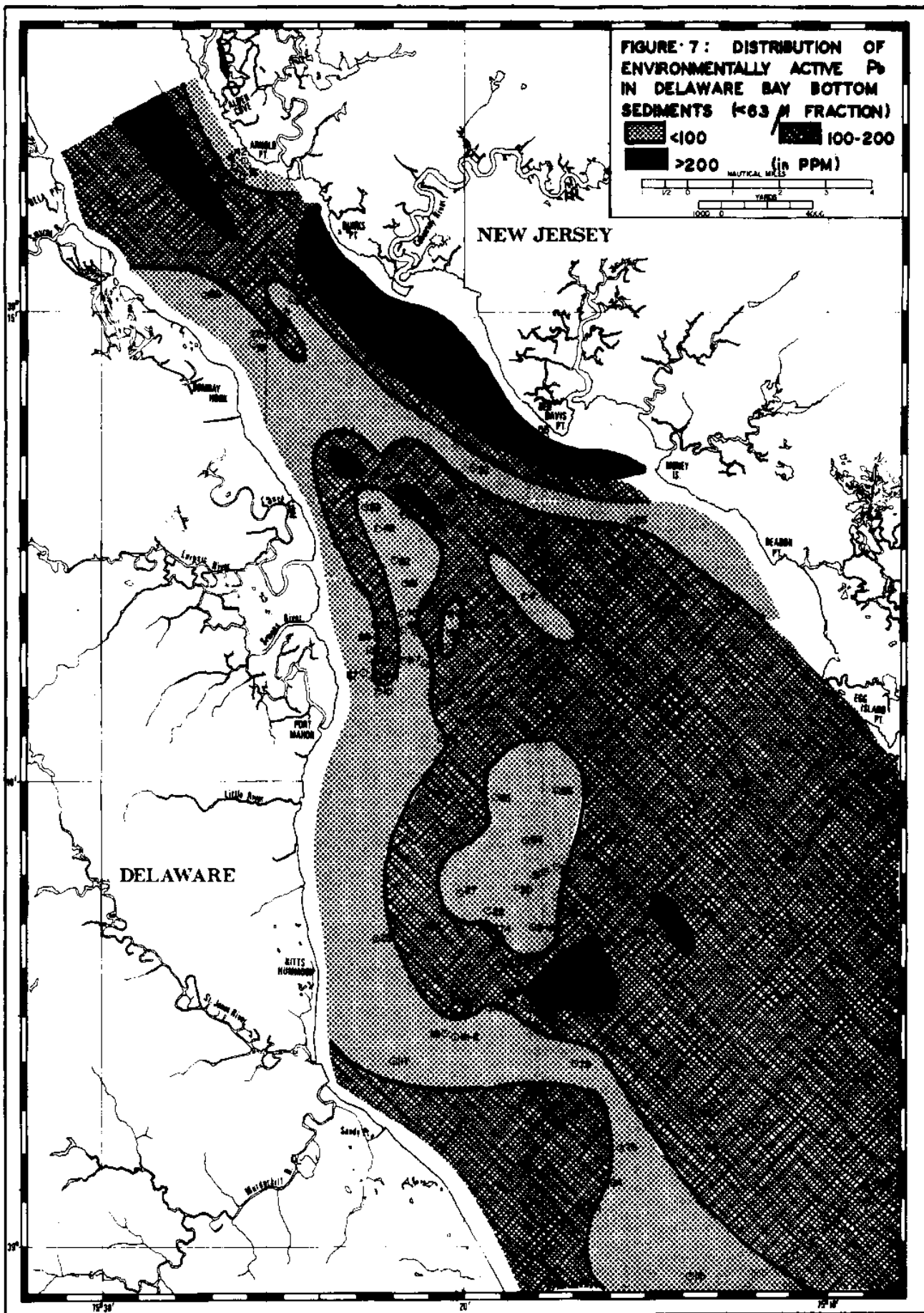
FIGURE 8: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Cd IN DELAWARE BAY BOTTOM SEDIMENTS (<63 μ FRACTION)

NEW JERSEY

DELAWARE
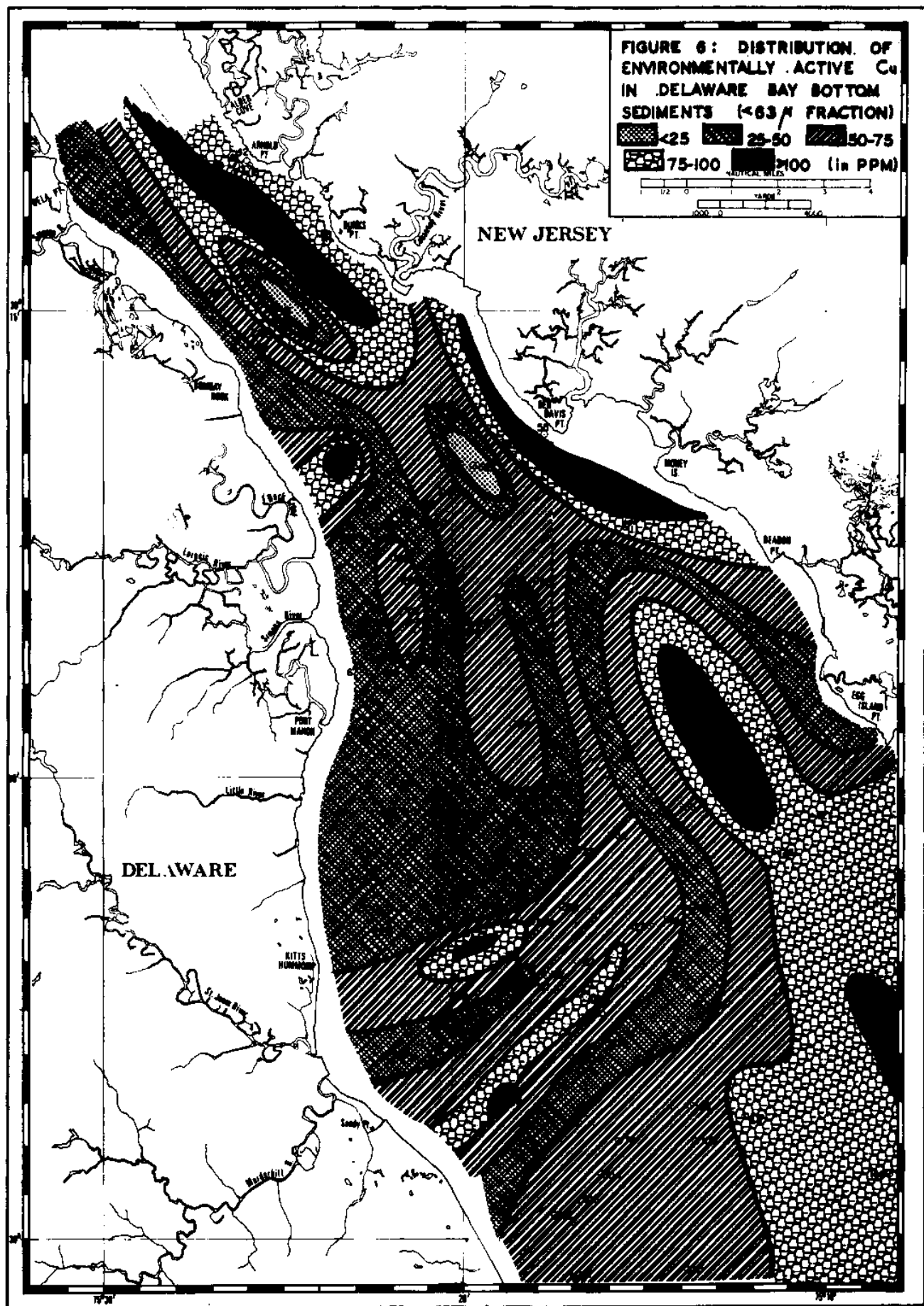
34

FIGURE 10: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Ni IN DELAWARE BAY BOTTOM SEDIMENTS (<63μ FRACTION)
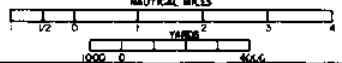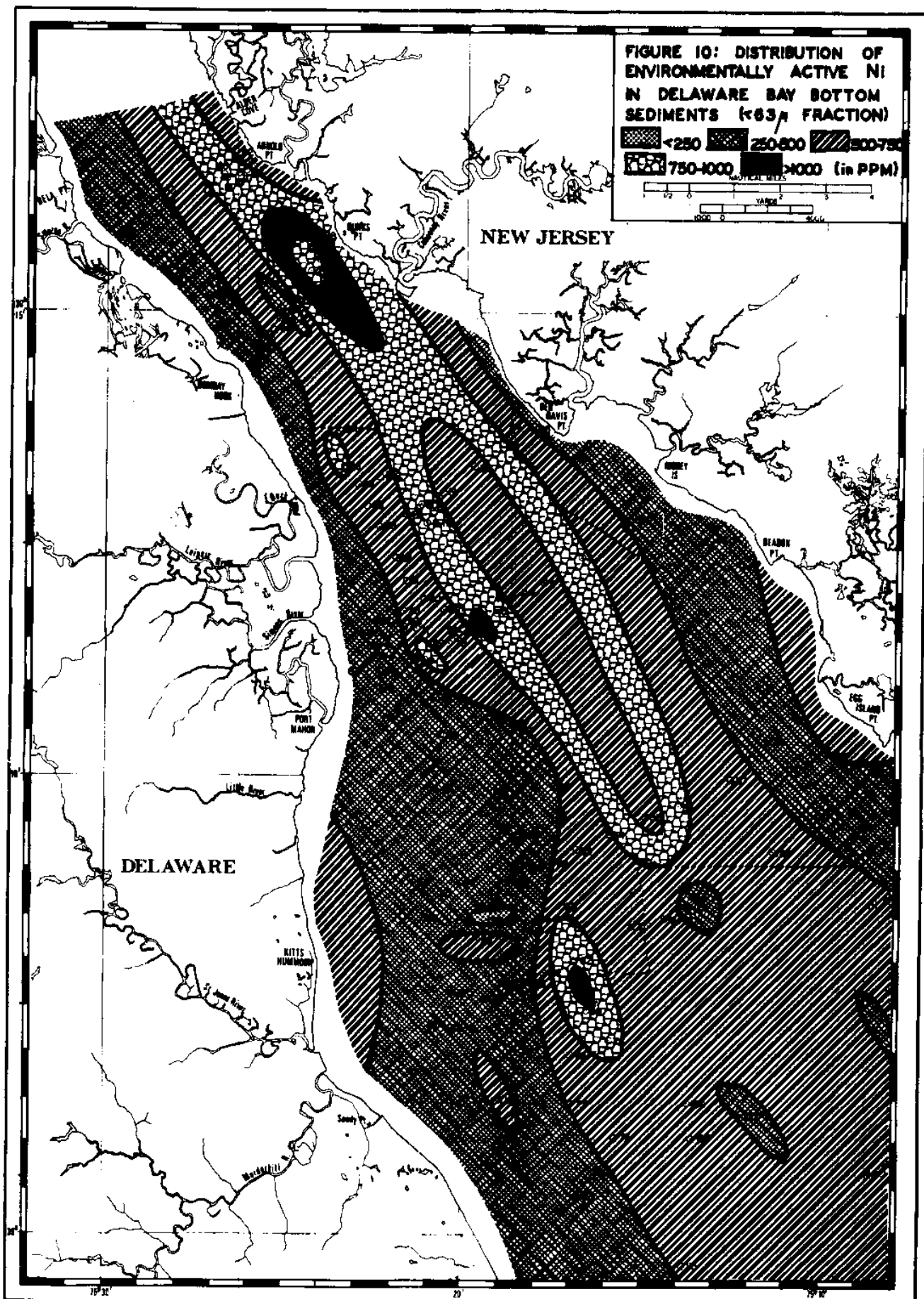
<250   250-500   500-750   750-1000   >1000 (in PPM)

NEW JERSEY

DELAWARE

FIGURE II: DISTRIBUTION OF ENVIRONMENTALLY ACTIVE Sr IN DELAWARE BAY BOTTOM SEDIMENTS (<63 μ FRACTION)

dissimilarity of the two regional diagrams presented as Figures 2

and 3. It seems apparent that the iron source is from the Delaware

River, while the magnesium source is primarily the ocean.

Figure 4 indicates an exceptionally straightforward pattern

in the distribution of zinc. It would seem that the primary source

of the zinc is the Delaware River. This is not hard to believe for

two reasons: 1) the high concentration of heavy industry in the vicinity

of Philadelphia, and 2) the prevalence of economic zinc ore deposits

in the Delaware drainage basin, most notably the huge deposit in

Franklin, New Jersey.

Figure 5 appears to indicate a predominantly seaborne source

for chromium, although high values in the upper reaches of the area

would suggest that there is also a substantial contribution from the

Delaware River. This also appears to be the case in Figure 6,

illustrating the distribution of copper in the Bay. Figure 7 indicates

that most of the lead in Delaware Bay sediments has its source in

the Delaware River, and that there is a substantial amount of mixing

in the middle reaches of the bay.

Although the data which comprise Figure 8 are the most suspect

in this report, it would appear that there is a cogent story to be

gleaned from the regional distribution of cadmium. It seems that the

principle source is the Delaware River, and that the mixing which

occurs in the lower and middle areas of this study has created a "sink"

of cadmium in the vicinity offshore from the points of entry into

the Bay of the Murderkill and St. Jones Rivers.

Judging by the distribution pattern for mercury in Figure 9, there is no doubt that the primary source of mercury is the Delaware River. Here again, mixing is occurring in the middle and lower reaches of the study area, although more restricted mixing than that experienced with cadmium. The same "sink" is also shown in Figure 9.

Figure 10, illustrating the distribution of trace nickel, indicates a primary source for nickel in the Delaware River, with a very straightforward distribution pattern. In Figure 11 one also sees a very straightforward pattern, although one which would indicate that the source of strontium in the Bay is the ocean with some limited mixing into the ebb tide side of the Bay along the Delaware shoreline.

In trying to answer the question of how much of any one of these metals is dangerous, toxic or lethal, one is hard pressed to quote rock-solid figures, even to the point of not wishing to hazard a guess. So little is currently known about the bio-chemistry of trace metals, that it is impossible to state what the danger levels are. One hopes that work on this type of an environmental problem is being pressed with all possible speed.

CONCLUSIONS

1) Trace metal geochemical aspects of the sedimentary environments which support oysters in Delaware have been typified for ten common trace metals. It is hoped that further work may

be accomplished in the foreseeable future which will expand the
results of this work.

2) The two hypotheses mentioned in the BACKGROUND section
of this report have been tested, and have been found not to be
mutually exclusive. That is, both of the processes mentioned
appear to be in operation. Fine-grained materials are being eroded
from the tidal marshes and are accumulating in the near-shore
bay area, where there are consistently low geochemical measurements.
There also exist conditions for the preferential deposition of fine-
grained materials carried into the Bay by the Delaware River, although
their deposition does not occur where originally hypothesized.
Deposition of river-borne materials occurs near the middle of the
navigational channel, and up to the New Jersey side of the Bay in the
uppermost reaches, and then approaches the Delaware side of the Bay
in the area between Port Mahon and the Murderkill and St. Jones River
mouths.

3) The characterization of the trace metals as to their
primary source and the major factor influencing their distribution
was made possible by Figures 2 through 11. It appears obvious
that iron, zinc, lead, cadmium, mercury and nickel have their
primary sources in the Delaware River, while magnesium, chromium,
copper and strontium have predominantly seaborne sources. It
also seems obvious that water currents are the principle factor
influencing the distribution of all of these metals, irrespective
of source area.

4) From Figures 5, 6, 7, and 11, it appears that there is a "hot spot" of high concentrations of chromium, copper, lead and strontium associated with the mouth of the Cohansey River in the northern extreme of the study area. Further investigation of this area should be undertaken to determine whether the area is a source for metal pollutants or a sink for metals borne by the Delaware River.

5) From Figures 2 through 11, it appears that there is a "sink" of trace metals being formed in the vicinity offshore from the mouths of the Murderkill and St. Jones Rivers. Further investigation of this area should be undertaken in order to ensure that shellfish taken from the region are within the U.S. Public Health Service limits of trace metals content.

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APPENDIX

Results of Emission Spectrophotometry, Reported in Parts

Per Million of the Finer than 63 Micron Sediment Fraction

SAMPLE ABBREVIATION KEY

Sample (from Table)	Sample Location
1	Bay Oyster Reef, B-1
2	Bay Oyster Reef, B-2
3	Bay Oyster Reef, B-3
4	Bay Oyster Reef, B-4
5	Bay Oyster Reef, B-5
6	Bay Oyster Reef, B-6
7	Bay Oyster Reef, B-7
8	Bay Oyster Reef, B-8
9	Bay Oyster Reef, B-9
10	Bay Oyster Reef, B-10
11	Bay Oyster Reef, B-11
12	Bay Oyster Reef, B-12
13	Bay Oyster Reef, B-13
14	Leipsic River West
15	Leipsic River East
16	Simon's Creek West
17	Simon's Creek East
18	St. Jones River West
19	St. Jones River East
20	Murderkill River East
21	Murderkill River West
22	Mispillion River West
23	Mispillion River East
24	Broadkill River West
25	Broadkill River East

"A" after a sample number indicates that it is a sediment sample from the finer than 63 micron fraction. "B" after a sample number indicates that it is a sample of dried and powdered oyster tissues from that location.

LOWER LIMITS OF DETECTION

Listed below are some of the lower limits of detection for some of the elements not listed in the accompanying table due to insufficient concentrations.

10,000 PPM: Li

5,000 PPM: Dy

1,000 PPM: As, Te, Ta, Tl, W

500 PPM: Ga, In, Ra, Tb

100 PPM: Hg, Sb, Pb, Mo, Th, Sn, V, Bi, Cd, Co

50 PPM: Pt, Pd, Ru, Hf, Rh, Ir, Y, Lu, La, Se, Gd, Tm, Er

10 PPM: Ge, Nb

5 PPM: Au, Yb, Ho

1 PPM: Be

SAMPLE	Fe	Mg	Ti	Ba	Mn	V	Cr	Zn
1A	>100,000	20,000	10,000	1,000	50,000	1,000	1,000	10,000
1B	1,000	5,000	100	<100	100	---	10,000	50,000
2A	>100,000	20,000	10,000	1,000	2,000	1,000	1,000	700
2B	3,000	10,000	300	<100	100	---	10,000	50,000
3A	---	---	---	---	---	---	---	---
3B	3,000	10,000	300	<100	200	---	10,000	30,000
4A	>100,000	20,000	10,000	1,000	2,000	1,000	<1,000	500
4B	3,000	5,000	300	<100	100	---	10,000	30,000
5A	>100,000	20,000	10,000	1,000	2,000	1,000	<1,000	300
5B	3,000	5,000	300	<100	100	---	10,000	50,000
6A	>100,000	30,000	10,000	1,000	20,000	1,000	1,000	7,000
6B	3,000	5,000	100	<100	100	---	10,000	50,000
7A	≥100,000	20,000	10,000	1,000	1,000	1,000	<1,000	200
7B	3,000	10,000	100	<100	300	---	10,000	30,000
8A	---	---	---	---	---	---	---	---
8B	3,000	20,000	100	<100	100	---	10,000	10,000
9A	≥100,000	20,000	10,000	1,000	1,000	1,000	<1,000	200
9B	20,000	10,000	200	<100	100	---	10,000	20,000
10A	≥100,000	20,000	10,000	1,000	1,000	1,000	<1,000	200
10B	2,000	10,000	200	<100	100	---	10,000	20,000
11A	---	---	---	---	---	---	---	---
11B	2,000	10,000	200	<100	100	---	10,000	≥100,000
12A	---	---	---	---	---	---	---	---
12B	2,000	10,000	200	<100	100	---	10,000	≥100,000
13A	≥100,000	15,000	10,000	1,000	1,000	1,000	<1,000	200
13B	2,000	10,000	200	<100	100	---	10,000	10,000
14A	100,000	10,000	10,000	1,000	800	1,000	<1,000	<100
14B	2,000	10,000	200	<100	100	---	10,000	≥100,000
15A	>100,000	30,000	10,000	1,000	1,000	1,000	<1,000	<100
15B	2,000	10,000	200	<100	100	---	10,000	≥100,000
16A	≥100,000	20,000	10,000	1,000	1,000	1,000	<1,000	100
16B	2,000	10,000	200	<100	100	---	10,000	≥100,000
17A	100,000	10,000	10,000	1,000	3,000	1,000	<1,000	200
17B	2,000	10,000	100	<150	100	---	10,000	60,000
18A	≥100,000	20,000	10,000	1,500	500	1,000	<1,000	200
18B	5,000	20,000	100	<100	100	---	10,000	20,000
19A	≥100,000	20,000	10,000	1,000	800	1,000	<1,000	200
19B	50,000	20,000	200	<100	100	---	10,000	20,000
20A	10,000	10,000	10,000	800	500	1,000	<1,000	<100
20B	5,000	20,000	200	<100	100	---	10,000	3,000
21A	>100,000	20,000	10,000	1,500	2,000	1,000	<1,000	<100
21B	5,000	20,000	200	<100	100	---	10,000	70,000
22A	---	---	---	---	---	---	---	---
22B	5,000	20,000	200	<100	100	---	10,000	10,000
23A	100,000	10,000	10,000	1,000	1,000	1,000	<1,000	100
23B	5,000	20,000	200	<100	100	---	10,000	10,000
24A	≥100,000	20,000	10,000	1,000	600	1,000	<1,000	<100
24B	5,000	20,000	500	<100	100	---	10,000	10,000
25A	≥100,000	20,000	10,000	1,000	500	1,000	<1,000	200
25B	5,000	20,000	100	<100	100	---	10,000	10,000

SAMPLE ABBREVIATION KEY

Sample (from Table)	Sample Location
1	Bay Oyster Reef, B-1
2	Bay Oyster Reef, B-2
3	Bay Oyster Reef, B-3
4	Bay Oyster Reef, B-4
5	Bay Oyster Reef, B-5
6	Bay Oyster Reef, B-6
7	Bay Oyster Reef, B-7
8	Bay Oyster Reef, B-8
9	Bay Oyster Reef, B-9
10	Bay Oyster Reef, B-10
11	Bay Oyster Reef, B-11
12	Bay Oyster Reef, B-12
13	Bay Oyster Reef, B-13
14	Leipsic River West
15	Leipsic River East
16	Simon's Creek West
17	Simon's Creek East
18	St. Jones River West
19	St. Jones River East
20	Murderkill River East
21	Murderkill River West
22	Mispillion River West
23	Mispillion River East
24	Broadkill River West
25	Broadkill River East

"A" after a sample number indicates that it is a sediment sample from the finer than 63 micron fraction. "B" after a sample number indicates that it is a sample of dried and powdered oyster tissues from that location.

LOWER LIMITS OF DETECTION

Listed below are some of the lower limits of detection for some of the elements not listed in the accompanying table due to insufficient concentrations.

10,000 PPM:	Li
5,000 PPM:	Dy
1,000 PPM:	As, Te, Ta, Tl, W
500 PPM:	Ga, In, Ra, Tb
100 PPM:	Hg, Sb, Pb, Mo, Th, Sn, V, Bi, Cd, Co
50 PPM:	Pt, Pd, Ru, Hf, Rh, Ir, Y, Lu, La, Se, Gd, Tm, Er
10 PPM:	Ge, Nb
5 PPM:	Au, Yb, Ho
1 PPM:	Be

SAMPLE	Pb	B	Cr	Ni	Cu	Sn	Ga	Co	Nb	La	Ag
1A	2,000	100	800	1,000	500	100	500	500	≤10	50	1
1B	---	10	<100	<100	2,000	---	---	---	---	--	100
2A	800	100	500	200	200	100	500	100	<10	50	1
2B	---	10	<100	<100	2,000	---	---	---	---	--	100
3A	---	---	---	---	---	---	---	---	---	--	---
3B	---	10	<100	<100	3,000	---	---	---	---	--	100
4A	800	100	300	200	200	100	500	100	<10	50	1
4B	---	≤10	<100	<100	1,000	---	---	---	---	--	100
5A	800	100	500	200	200	100	500	100	<10	50	≤1
5B	---	10	<100	<100	2,000	---	---	---	---	--	100
6A	1,000	100	500	500	300	100	500	100	<10	50	1
6B	---	10	<100	<100	3,000	---	---	---	---	--	100
7A	200	100	500	200	500	100	500	100	≤10	50	1
7B	---	10	<100	<100	1,000	---	---	---	---	--	50
8A	---	---	---	---	---	---	---	---	---	--	---
8B	---	10	<100	<100	1,000	---	---	---	---	--	50
9A	200	100	500	200	500	100	500	100	≤10	50	≤1
9B	---	10	<100	<100	500	---	---	---	---	--	10
10A	200	100	500	200	300	100	500	100	≤10	50	≤1
10B	---	10	<100	<100	500	---	---	---	---	--	10
11A	---	---	---	---	---	---	---	---	---	--	---
11B	---	10	<100	<100	2,000	---	---	---	---	--	100
12A	---	---	---	---	---	---	---	---	---	--	---
12B	---	10	<100	<100	1,000	---	---	---	---	--	100
13A	250	100	500	150	250	100	500	100	≤10	50	1
13B	---	10	<100	<100	1,000	---	---	---	---	--	10
14A	100	100	200	200	200	<100	500	100	<10	50	<1
14B	---	10	<100	<100	1,000	---	---	---	---	--	100
15A	200	100	500	200	300	<100	500	100	<10	50	<1
15B	---	10	<100	<100	1,000	---	---	---	---	--	100
16A	300	100	400	200	500	100	500	100	<10	50	1
16B	---	10	<100	<100	1,000	---	---	---	---	--	100
17A	400	100	400	200	500	100	500	100	<10	50	1
17B	---	10	<100	≤100	1,000	---	---	---	---	--	50
18A	200	100	500	200	1,000	100	500	100	<10	50	<1
18B	---	10	<100	≤100	500	---	---	---	---	--	10
19A	200	100	500	200	500	≤100	500	100	≤10	50	2
19B	---	10	<100	≤100	500	---	---	---	---	--	10
20A	200	100	200	200	1,000	100	500	100	<10	50	<1
20B	---	10	<100	<100	200	---	---	---	---	--	10
21A	200	100	500	200	200	100	500	100	<10	50	<1
21B	---	10	<100	<100	500	---	---	---	---	--	10
22A	---	---	---	---	---	---	---	---	---	--	---
22B	---	10	<100	<100	500	---	---	---	---	--	10
23A	200	100	200	200	200	<100	500	100	<10	50	<1
23B	---	10	<100	<100	1,000	---	---	---	---	--	20
24A	200	100	200	200	100	<100	500	100	<10	50	<1
24B	---	10	<100	<100	500	---	---	---	---	--	20
25A	200	100	500	200	500	100	500	100	≤10	50	1
25B	---	30	<100	<100	500	---	---	---	---	--	10